

LA-UR-21-31738

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Title: (U) Using the MCNP6 Perturbation Capability for Source Nuclide Density
Sensitivities

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Intended for: Report

Issued: 2021-12-01

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memorandum

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Symbol: XCP-7:21-018(U)
Date: November 30, 2021

SUBJECT: (U) Using the MCNP6 Perturbation Capability for Source Nuclide Density Sensitivities

I. Introduction

The Taylor series (differential operator) perturbation method, as implemented in the PERT capability in MCNP6 (Ref. 1), can be used for first- and second-order sensitivity analyses in fixed-source problems.² Unfortunately, the PERT capability does not yet work with point-detector (F5) or pulse-height (F8) tallies. Also, the second-order Taylor series term lacks the cross terms that would allow the calculation of mixed sensitivities.³ Finally, the PERT capability does not compute any sensitivities involving the source in a fixed-source problem. When neutrons or gamma rays are emitted due to radioactive decay, the source rate density depends intrinsically on the nuclide densities in the source material. When the PERT capability in MCNP6 is used to compute sensitivities of a response to nuclide and material densities, those sensitivities do not include the effect of the source.

This report discusses how to compute sensitivities of a response to source nuclide densities in order to allow MCNP6's PERT capability to compute the full sensitivity of a response to nuclide and material densities.

This report is organized as follows. Section II presents the transport equation and establishes notation. Section III discusses the sensitivity of a response to nuclide densities. Section IV introduces the method to use MCNP6 to compute source nuclide density sensitivities. Section V is a test problem. Section VI is a summary. Input files for the test problem are listed in the appendix.

II. Transport Equation and Response

The transport equation for the neutral particle angular flux Ψ can be written

$$A\Psi = Q, \quad (1)$$

where the transport operator A includes streaming, total interactions, scattering, and fission, and Q is the inhomogeneous source rate density. The response of interest R is

$$R = \langle \Sigma_d \Psi \rangle, \quad (2)$$

where Σ_d is a response function and the angle brackets indicate an integral over volume, energy, and angle.

In this paper, the inhomogeneous source rate density Q is produced from radioactive decay of the nuclides in the source material. The total source rate density Q is the sum of the source rate density from each of the Z contributions to the source:

$$Q = \sum_{z=1}^Z Q_z. \quad (3)$$

Intrinsic sources from radioactive decay are computed with codes like MISC (Ref. 4) and SOURCES4C (Ref. 5) and then written to an MCNP6 input file. Contributions can be direct emissions from a decay, or they can be neutrons emitted from (α, n) reactions, in which case index z designates a particular source/target combination.⁵ The principle of superposition can be used to write the transport equation for each Q_z , $z = 1, \dots, Z$. The angular flux Ψ in Eq. (1) is the sum of the Z solutions Ψ_z , and the response R is

$$R = \sum_{z=1}^Z R_z, \quad (4)$$

where

$$R_z = \langle \Sigma_d \Psi_z \rangle, z = 1, \dots, Z. \quad (5)$$

III. Sensitivity to Nuclide Density

The relative sensitivity S_{R,N_i} of response R with respect to the density N_i of nuclide $i = 1, \dots, I$ in the source material is

$$S_{R,N_i} \equiv \frac{N_i}{R} \frac{\partial R}{\partial N_i}. \quad (6)$$

The angular flux and therefore the response depend on the source nuclide atom density through the cross sections in the transport operator A and through the parameters in the source rate density Q . Let A_m , $m = 1, \dots, M$, represent the parameters in A that depend on N_i . Using the total derivative in Eq. (6) and using Eq. (4) yields

$$S_{R,N_i} = \frac{N_i}{R} \left(\sum_{m=1}^M \frac{\partial R}{\partial A_m} \frac{\partial A_m}{\partial N_i} + \sum_{z=1}^Z \frac{\partial R_z}{\partial Q_z} \frac{\partial Q_z}{\partial N_i} \right). \quad (7)$$

Because the transport operator is linear, we have

$$\frac{\partial R_z}{\partial Q_z} = \frac{R_z}{Q_z}. \quad (8)$$

Equation (7) becomes

$$S_{R,N_i} = \frac{N_i}{R} \sum_{m=1}^M \frac{\partial R}{\partial A_m} \frac{\partial A_m}{\partial N_i} + \sum_{z=1}^Z \frac{R_z}{Q_z} \frac{N_i}{R} \frac{\partial Q_z}{\partial N_i}. \quad (9)$$

Define the contributions due to the transport operator and the source separately as

$$S_{R(A),N_i} \equiv \frac{N_i}{R} \sum_{m=1}^M \frac{\partial R}{\partial A_m} \frac{\partial A_m}{\partial N_i} \quad (10)$$

and

$$S_{R(Q_z),N_i} \equiv \frac{R_z}{R} \frac{N_i}{Q_z} \frac{\partial Q_z}{\partial N_i}, \quad (11)$$

respectively. Equation (9) becomes

$$S_{R,N_i} = S_{R(A),N_i} + \sum_{z=1}^Z S_{R(Q_z),N_i}. \quad (12)$$

Often, the source rate density Q_z due to nuclide i is proportional to the density of nuclide i . For example, the total neutron source rate density due to spontaneous fission of nuclide i is⁵

$$Q_{s.f.,i} = \lambda_i N_i S_i(s.f.), \quad (13)$$

where λ_i is the decay constant and $S_i(s.f.)$ is the average number of spontaneous-fission neutrons produced per decay of nuclide i . The derivative of $Q_{s.f.,i}$ is

$$\frac{\partial Q_{s.f.,i}}{\partial N_i} = \lambda_i S_i(s.f.) = \frac{Q_{s.f.,i}}{N_i}. \quad (14)$$

Whenever the source rate density Q_z due to nuclide i is proportional to the density of nuclide i , we have

$$\frac{N_i}{Q_z} \frac{\partial Q_z}{\partial N_i} = 1, \quad (15)$$

and Eq. (11) becomes

$$S_{R(Q_z),N_i} = \frac{R_z}{R}. \quad (16)$$

The neutron source rate density from (α, n) reactions is not proportional to any nuclide densities.^{5,6} The derivative of an (α, n) source rate density with respect to each source material nuclide density is given in Ref. 6. Suffice it to say here that every nuclide in a material contributes to the (α, n) source rate density, some because they are α particle sources, some because they are (α, n) targets, and all because they contribute to the material's stopping power for α particles.

IV. Computing the Source Sensitivity

The MCNP6 Taylor series perturbation capability provides a Monte Carlo estimate of $S_{R(A),N_i}$ of Eq. (10). It provides no estimate of $S_{R(Q_z),N_i}$ of Eq. (11). However, Eq. (11) can be computed outside the PERT capability.

The derivative $(N_i / Q_z)(\partial Q_z / \partial N_i)$ is computed using data from the intrinsic source calculation, i.e. MISC, SOURCES4C, or a similar code.

Source z 's relative contribution to the total response, R_z / R , is computed using a standard feature of MCNP6, the “special tally treatment” or FT card with the SCX keyword that “identifies the sampled index of a specified source distribution.”¹ The way to do this is to set up a unique distribution for each of the source contributions Q_z , $z=1,\dots,Z$. Let one source variable be sampled from a set of Z

distributions using the “s” option on the SI card, and the probabilities on the SP card would be the total strengths of each of the Z sources. Let the other source variables be dependent distributions, unless they are all the same for all Z sources. The “FT SCX” card then contains the distribution number given on the SI card. An example is given in the next section.

V. Test Problem

The test problem is a small homogeneous bare PuO₂ sphere with a radius of 4.4 cm. The composition is shown in Table I. The material mass density is 9.533052 g/cm³.

Table I. Composition of PuO₂ Material.

Component	Mass (g)	Atom Density (/b/cm)
²³⁸ Pu	1.982149	1.405313514E-05
²³⁹ Pu	2990.000000	2.110973593E-02
²⁴⁰ Pu	5.033104	3.538601590E-05
²⁴² Pu	2.984747	2.081093907E-05
¹⁶ O	400.476171	4.225704060E-02
¹⁷ O	0.163623	1.624508343E-05
¹⁸ O	0.923840	8.662630124E-05
Total	3401.563634	6.353989800E-02

In this material, there are 12 contributions to the neutron source. Spontaneous-fission and (α, n) neutron source rate densities were computed using a modified version of SOURCES4C (Ref. 5) that outputs the quantities needed to compute nuclide density derivatives in post-processing.⁶ The 12 source rate densities and the total are shown in Table II. The masses of ²³⁸Pu, ²⁴⁰Pu, and ²⁴²Pu in the test material were chosen so that the spontaneous fission source from these isotopes would be approximately equal.

Table II. Neutron Sources and Responses in the PuO₂ Material.

<i>z</i>	Component	<i>Q_z</i> (/cm ³ /s)	<i>R_z</i> (/s) ^(a)
1	²³⁸ Pu (α, n) on ¹⁷ O	6.2435E+00	3.3496E+03
2	²³⁹ Pu (α, n) on ¹⁷ O	2.6202E+01	1.4075E+04
3	²⁴⁰ Pu (α, n) on ¹⁷ O	1.6229E-01	8.7173E+01
4	²⁴² Pu (α, n) on ¹⁷ O	1.3623E-03	7.3262E-01
5	²³⁸ Pu (α, n) on ¹⁸ O	7.2428E+01	3.8882E+04
6	²³⁹ Pu (α, n) on ¹⁸ O	3.1103E+02	1.6689E+05
7	²⁴⁰ Pu (α, n) on ¹⁸ O	1.9534E+00	1.0480E+03
8	²⁴² Pu (α, n) on ¹⁸ O	1.6692E-02	8.9546E+00
9	²³⁸ Pu spont. fission	1.4447E+01	7.6624E+03
10	²³⁹ Pu spont. fission	1.2462E-01	6.6151E+01
11	²⁴⁰ Pu spont. fission	1.4738E+01	7.8047E+03
12	²⁴² Pu spont. fission	1.4469E+01	7.6659E+03
	Total	4.6182E+02	2.4754E+05

(a) The relative uncertainty is 0.004 % for all components and 0.003 % for the total.

The quantity of interest was the neutron leakage from the sphere. The leakage was calculated using a version of MCNP6 that was slightly modified to print more digits in the relative uncertainty.

The tally contributions R_z , $z = 1, \dots, Z$, were computed as shown in Fig. 1. The energy ERG is given on distribution 2. The “s” option on the SI2 card means that each of the $Z = 12$ entries is a distribution. The probabilities on the SP2 card are the source rate densities for the 12 sources as given by SOURCES4C. (The source rate densities rather than source rates are used here because all of the sources are in the same volume.) The total source weight WGT is the sum of the source rate densities multiplied by the source volume. Each of the distributions 3 through 14 is the spectrum for each of the 12 sources, copied from the tape7 file of the SOURCES4C output.

```
f1:n 1
ft1 scx 2
sdef pos=0. 0. 0. rad=d1 erg=d2 wgt=1.647949221E+05
si1 0. 4.40
sp1 -21 2
sc2 n/s/cm^3
si2 s 3 4 5 6 7 8 9 10 11 12 13 14
sp2 6.2434764E+00 2.6201909E+01 1.6228581E-01 1.3623085E-03
7.2427935E+01 3.1103387E+02 1.9534423E+00 1.6691787E-02
1.4447102E+01 1.2462036E-01 1.4737994E+01 1.4468765E+01
sb2 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.
sc3 pu238 alphas on o 17
# si3 sp3
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 0.0000000E+00
4.1400000E-07 0.0000000E+00
1.1300000E-06 0.0000000E+00
3.0600000E-06 0.0000000E+00
8.3200000E-06 6.2598710E-08
2.2600000E-05 2.9673969E-07
& 1.000000E-05 9.0626751E-07
```

Figure 1. Snippet of MCNP6 input file showing the tally and part of the source definition. The full input file is listed in the appendix.

The tally, shown at the top of Fig. 1, is a current (F1) tally with an FT SCX treatment for distribution 2. The result is that the output shows the contribution from each of the 12 distributions on the SI2 card and the total. These 13 values are shown in Table II.

The derivative $(N_i / Q_z)(\partial Q_z / \partial N_i)$ is shown for each of the $I = 7$ nuclides and $Z = 12$ sources in Table III. The derivative $(N / Q_z)(\partial Q_z / \partial N)$, where $N = \sum_{i=1}^I N_i$ is the total material atom density, is also shown; it is equal to 1, as derived in Ref. 6.

Table III. $(N_i / Q_z)(\partial Q_z / \partial N_i)$ and $(N / Q_z)(\partial Q_z / \partial N)$ for the PuO₂ Material.

z	²³⁸ Pu	²³⁹ Pu	²⁴⁰ Pu	²⁴² Pu	¹⁶ O	¹⁷ O	¹⁸ O	Mat.
1	9.9972E-01	-6.9225E-01	-1.1604E-03	-6.8245E-04	-3.0489E-01	1.0001E+00	-6.2502E-04	1
2	-4.5975E-04	3.0939E-01	-1.1577E-03	-6.8083E-04	-3.0635E-01	9.9988E-01	-6.2801E-04	1
3	-4.5977E-04	-6.9064E-01	9.9884E-01	-6.8086E-04	-3.0632E-01	9.9988E-01	-6.2794E-04	1
4	-4.5899E-04	-6.8946E-01	-1.1557E-03	9.9932E-01	-3.0750E-01	9.9988E-01	-6.3037E-04	1
5	9.9966E-01	-6.9264E-01	-1.1611E-03	-6.8284E-04	-3.0443E-01	-1.1704E-04	9.9950E-01	1
6	-4.6019E-04	3.0879E-01	-1.1588E-03	-6.8148E-04	-3.0575E-01	-1.1754E-04	9.9943E-01	1
7	-4.6015E-04	-6.9121E-01	9.9886E-01	-6.8143E-04	-3.0576E-01	-1.1754E-04	9.9939E-01	1
8	-4.5957E-04	-6.9034E-01	-1.1572E-03	9.9934E-01	-3.0664E-01	-1.1788E-04	9.9939E-01	1
9	1	0	0	0	0	0	0	1
10	0	1	0	0	0	0	0	1
11	0	0	1	0	0	0	0	1
12	0	0	0	1	0	0	0	1

The relative sensitivities $S_{R(A),N_i}$ of Eq. (10) are computed using the MCNP6 PERT capability according to the prescription given in Ref. 2. Sensitivities are shown in Table IV and compared with adjoint-based values computed using the multigroup discrete ordinates code SENSEMG (Ref. 7) with 30 energy groups, S₂₅₆ quadrature, and P_3 scattering. Exact agreement is not expected because the calculations are different, but the agreement achieved is excellent. The 12 source spectra in the MCNP6 calculation are given in the same 30 energy groups used in the SENSEMG calculation.

Table IV. $S_{R(A),N_i}$ and $S_{R(A),N}$ (%/%).

Nuclide	PERT	SENSEMG
²³⁸ Pu	4.0703E-04 ± 1.03E-06	4.0697E-04
²³⁹ Pu	5.5362E-01 ± 6.30E-05	5.5514E-01
²⁴⁰ Pu	7.1056E-04 ± 1.46E-06	7.0953E-04
²⁴² Pu	3.6284E-04 ± 1.08E-06	3.6202E-04
¹⁶ O	3.3695E-02 ± 2.03E-05	3.5749E-02
¹⁷ O	-6.2082E-07 ± 2.92E-07	-6.4448E-08
¹⁸ O	1.3482E-04 ± 1.15E-06	1.3326E-04
Mat.	5.8893E-01 ± 6.95E-05	5.9250E-01

The relative sensitivities $S_{R(Q_z),N_i}$ of Eq. (11) are computed using values from Tables II and III. Sensitivities are shown in Table V and compared with values computed using SENSEMG. The agreement achieved is excellent.

Table V. $\sum_{z=1}^Z S_{R(Q_z),N_i}$ and $\sum_{z=1}^Z S_{R(Q_z),N}$ (%/%).

Nuclide	This Paper, Eq. (11)	SENSMG
^{238}Pu	2.0116E-01	2.0115E-01
^{239}Pu	1.0469E-01	1.0468E-01
^{240}Pu	3.5064E-02	3.5068E-02
^{242}Pu	3.0389E-02	3.0392E-02
^{16}O	-2.7691E-01	-2.7689E-01
^{17}O	7.0640E-02	7.0629E-02
^{18}O	8.3503E-01	8.3497E-01
Mat.	1.0000E+00	1.0000E+00

Finally, the relative sensitivities S_{R,N_i} of Eq. (6), which are the goal of this paper, are computed using the sensitivities in Tables IV and V. Sensitivities are shown in Table VI and compared with values computed using SENS MG. The agreement achieved is excellent.

Table VI. S_{R,N_i} and $S_{R,N}$ (%/%).

Nuclide	This Paper, Eq. (12)	SENSMG
^{238}Pu	2.0157E-01 \pm 1.03E-06	2.0156E-01
^{239}Pu	6.5831E-01 \pm 6.30E-05	6.5982E-01
^{240}Pu	3.5775E-02 \pm 1.46E-06	3.5778E-02
^{242}Pu	3.0752E-02 \pm 1.08E-06	3.0754E-02
^{16}O	-2.4322E-01 \pm 2.03E-05	-2.4114E-01
^{17}O	7.0640E-02 \pm 2.92E-07	7.0629E-02
^{18}O	8.3516E-01 \pm 1.15E-06	8.3510E-01
Mat.	1.5889E+00 \pm 6.95E-05	1.5925E+00

VI. Summary and Conclusions

Application of the MCNP6 Taylor series perturbation capability for density sensitivities has been limited because changing nuclide or material densities frequently changes the intrinsic source, and the PERT capability has no way of accounting for this effect. This report shows how to use the results of the intrinsic source calculation, along with the SCX special tally treatment (FT) in MCNP6, to compute the full nuclide density first-order sensitivities.

The PERT capability can compute the second derivative of a response with respect to nuclide densities,^{1,2} but again only for the transport terms, and not mixed second derivatives. Second derivatives of (α,n) sources with respect to nuclide densities have been derived.⁸ (The second derivative of a spontaneous-fission source with respect to nuclide density is zero.) It may be possible to apply a method similar to that used in this paper to compute the full second-order sensitivity of a response to a source nuclide.

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XCP-7 File

Appendix

Input File Listings for the Test Problem

MCNP6 Input File

```
multiple spont. fiss. and (alpha,n) sources
1   1      6.353989800E-02      -1      imp:n=1
9   0                  1      imp:n=0

1   so     4.40

mode n
nps 2e10
prdmp j 2e9
rand gen=2 seed=1001
idum 1 $ print more digits for relative uncertainty
m1    nlib=00c
      94238  1.405313514E-05
      94239  2.110973593E-02
      94240  3.538601590E-05
      94242  2.081093907E-05
      8016   4.225704060E-02
      8017   1.624508343E-05
      8018   8.662630124E-05
m11   nlib=00c $ 6.355395114E-02
      94238  2.810627028E-05
      94239  2.110973593E-02
      94240  3.538601590E-05
      94242  2.081093907E-05
      8016   4.225704060E-02
      8017   1.624508343E-05
      8018   8.662630124E-05
m12   nlib=00c $ 8.464963393E-02
      94238  1.405313514E-05
      94239  4.221947186E-02
      94240  3.538601590E-05
      94242  2.081093907E-05
      8016   4.225704060E-02
      8017   1.624508343E-05
      8018   8.662630124E-05
m13   nlib=00c $ 6.357528402E-02
      94238  1.405313514E-05
      94239  2.110973593E-02
      94240  7.077203180E-05
      94242  2.081093907E-05
      8016   4.225704060E-02
      8017   1.624508343E-05
      8018   8.662630124E-05
m14   nlib=00c $ 6.356070894E-02
      94238  1.405313514E-05
      94239  2.110973593E-02
      94240  3.538601590E-05
      94242  4.162187814E-05
      8016   4.225704060E-02
      8017   1.624508343E-05
      8018   8.662630124E-05
m15   nlib=00c $ 1.057969386E-01
      94238  1.405313514E-05
      94239  2.110973593E-02
      94240  3.538601590E-05
      94242  2.081093907E-05
      8016   8.451408120E-02
      8017   1.624508343E-05
      8018   8.662630124E-05
m16   nlib=00c $ 6.355614309E-02
      94238  1.405313514E-05
      94239  2.110973593E-02
      94240  3.538601590E-05
      94242  2.081093907E-05
      8016   4.225704060E-02
      8017   3.249016686E-05
```

```
8018 8.662630124E-05
m17 nlib=00c $ 6.362652431E-02
94238 1.405313514E-05
94239 2.110973593E-02
94240 3.538601590E-05
94242 2.081093907E-05
8016 4.225704060E-02
8017 1.624508343E-05
8018 1.732526025E-04
pert1:n cell=1 mat=11 rho=6.355395114E-02 method=2
pert2:n cell=1 mat=12 rho=8.464963393E-02 method=2
pert3:n cell=1 mat=13 rho=6.357528402E-02 method=2
pert4:n cell=1 mat=14 rho=6.356070894E-02 method=2
pert5:n cell=1 mat=15 rho=1.057969386E-01 method=2
pert6:n cell=1 mat=16 rho=6.355614309E-02 method=2
pert7:n cell=1 mat=17 rho=6.362652431E-02 method=2
pert8:n cell=1 rho=1.270797960E-01 method=2
f1:n 1
ft1 scx 2
sdef pos=0. 0. 0. rad=d1 erg=d2 wgt=1.647949221E+05
sil 0. 4.40
sp1 -21 2
sc2 n/s/cm^3
si2 s 3 4 5 6 7 8 9 10 11 12 13 14
sp2 6.2434764E+00 2.6201909E+01 1.6228581E-01 1.3623085E-03
7.2427935E+01 3.1103387E+02 1.9534423E+00 1.6691787E-02
1.4447102E+01 1.2462036E-01 1.4737994E+01 1.4468765E+01
sb2 1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.
sc3 pu238 alphas on o 17
# si3 sp3
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 0.0000000E+00
4.1400000E-07 0.0000000E+00
1.1300000E-06 0.0000000E+00
3.0600000E-06 0.0000000E+00
8.3200000E-06 6.2598710E-08
2.2600000E-05 2.9673969E-07
6.1400000E-05 8.0626751E-07
1.6700000E-04 2.1943776E-06
4.5400000E-04 5.9638862E-06
1.2350000E-03 1.6229252E-05
3.3500000E-03 1.3903648E-04
9.1200000E-03 4.5366015E-04
2.4800000E-02 2.1553890E-03
6.7600000E-02 9.3675802E-03
1.8400000E-01 4.4947188E-02
3.0300000E-01 7.3065965E-02
5.0000000E-01 1.7481395E-01
8.2300000E-01 2.6425865E-01
1.3530000E+00 3.3028393E-01
1.7380000E+00 5.1690225E-01
2.2320000E+00 9.9377830E-01
2.8650000E+00 1.5414184E+00
3.6800000E+00 1.4209770E+00
6.0700000E+00 8.7088953E-01
7.7900000E+00 0.0000000E+00
1.0000000E+01 0.0000000E+00
1.2000000E+01 0.0000000E+00
1.3500000E+01 0.0000000E+00
1.5000000E+01 0.0000000E+00
1.7000000E+01 0.0000000E+00
sc4 pu239 alphas on o 17
# si4 sp4
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 0.0000000E+00
4.1400000E-07 0.0000000E+00
1.1300000E-06 0.0000000E+00
3.0600000E-06 0.0000000E+00
8.3200000E-06 0.0000000E+00
2.2600000E-05 0.0000000E+00
6.1400000E-05 0.0000000E+00
1.6700000E-04 0.0000000E+00
```

4.5400000E-04	0.0000000E+00
1.2350000E-03	3.1349776E-05
3.3500000E-03	5.1383127E-04
9.1200000E-03	1.6264432E-03
2.4800000E-02	8.1287314E-03
6.7600000E-02	4.4082632E-02
1.8400000E-01	2.2559272E-01
3.0300000E-01	3.5406419E-01
5.0000000E-01	5.0889506E-01
8.2300000E-01	5.8865898E-01
1.3530000E+00	1.2379656E+00
1.7380000E+00	2.7445347E+00
2.2320000E+00	5.4447763E+00
2.8650000E+00	6.9085180E+00
3.6800000E+00	5.2442456E+00
6.0700000E+00	2.8902748E+00
7.7900000E+00	0.0000000E+00
1.0000000E+01	0.0000000E+00
1.2000000E+01	0.0000000E+00
1.3500000E+01	0.0000000E+00
1.5000000E+01	0.0000000E+00
1.7000000E+01	0.0000000E+00
sc5 pu240 alphas on o 17	
# si5 sp5	
0.0000000E+00	0.0000000E+00
1.3900000E-10	0.0000000E+00
1.5200000E-07	0.0000000E+00
4.1400000E-07	0.0000000E+00
1.1300000E-06	0.0000000E+00
3.0600000E-06	0.0000000E+00
8.3200000E-06	0.0000000E+00
2.2600000E-05	0.0000000E+00
6.1400000E-05	0.0000000E+00
1.6700000E-04	4.5289519E-08
4.5400000E-04	2.0085610E-07
1.2350000E-03	5.4658055E-07
3.3500000E-03	1.8535082E-06
9.1200000E-03	1.0129349E-05
2.4800000E-02	5.0118865E-05
6.7600000E-02	2.6526550E-04
1.8400000E-01	1.3914583E-03
3.0300000E-01	2.2072670E-03
5.0000000E-01	3.2189214E-03
8.2300000E-01	3.6750913E-03
1.3530000E+00	7.7027414E-03
1.7380000E+00	1.6954113E-02
2.2320000E+00	3.3494393E-02
2.8650000E+00	4.2737136E-02
3.6800000E+00	3.2610539E-02
6.0700000E+00	1.7965985E-02
7.7900000E+00	0.0000000E+00
1.0000000E+01	0.0000000E+00
1.2000000E+01	0.0000000E+00
1.3500000E+01	0.0000000E+00
1.5000000E+01	0.0000000E+00
1.7000000E+01	0.0000000E+00
sc6 pu242 alphas on o 17	
# si6 sp6	
0.0000000E+00	0.0000000E+00
1.3900000E-10	0.0000000E+00
1.5200000E-07	0.0000000E+00
4.1400000E-07	0.0000000E+00
1.1300000E-06	0.0000000E+00
3.0600000E-06	0.0000000E+00
8.3200000E-06	0.0000000E+00
2.2600000E-05	0.0000000E+00
6.1400000E-05	0.0000000E+00
1.6700000E-04	0.0000000E+00
4.5400000E-04	0.0000000E+00
1.2350000E-03	1.6249704E-09
3.3500000E-03	3.2937279E-08
9.1200000E-03	1.0900170E-07
2.4800000E-02	5.0007613E-07
6.7600000E-02	2.8458075E-06

1.8400000E-01	1.1958218E-05
3.0300000E-01	1.0699592E-05
5.0000000E-01	1.1082024E-05
8.2300000E-01	1.5072840E-05
1.3530000E+00	7.8940230E-05
1.7380000E+00	1.7284590E-04
2.2320000E+00	3.3705644E-04
2.8650000E+00	3.5538337E-04
3.6800000E+00	2.2983482E-04
6.0700000E+00	1.3594565E-04
7.7900000E+00	0.0000000E+00
1.0000000E+01	0.0000000E+00
1.2000000E+01	0.0000000E+00
1.3500000E+01	0.0000000E+00
1.5000000E+01	0.0000000E+00
1.7000000E+01	0.0000000E+00
sc7 pu238 alphas on o 18	
# si7 sp7	
0.0000000E+00	0.0000000E+00
1.3900000E-10	0.0000000E+00
1.5200000E-07	0.0000000E+00
4.1400000E-07	0.0000000E+00
1.1300000E-06	0.0000000E+00
3.0600000E-06	0.0000000E+00
8.3200000E-06	0.0000000E+00
2.2600000E-05	0.0000000E+00
6.1400000E-05	1.1662040E-05
1.6700000E-04	4.0880555E-05
4.5400000E-04	2.0431748E-04
1.2350000E-03	5.6663149E-04
3.3500000E-03	1.5382677E-03
9.1200000E-03	8.3270888E-03
2.4800000E-02	3.7017024E-02
6.7600000E-02	1.5421865E-01
1.8400000E-01	6.3225674E-01
3.0300000E-01	7.0437547E-01
5.0000000E-01	1.2273428E+00
8.2300000E-01	2.3108638E+00
1.3530000E+00	5.0205983E+00
1.7380000E+00	6.1223426E+00
2.2320000E+00	1.2827796E+01
2.8650000E+00	2.1193646E+01
3.6800000E+00	1.8032063E+01
6.0700000E+00	4.1547250E+00
7.7900000E+00	0.0000000E+00
1.0000000E+01	0.0000000E+00
1.2000000E+01	0.0000000E+00
1.3500000E+01	0.0000000E+00
1.5000000E+01	0.0000000E+00
1.7000000E+01	0.0000000E+00
sc8 pu239 alphas on o 18	
# si8 sp8	
0.0000000E+00	0.0000000E+00
1.3900000E-10	0.0000000E+00
1.5200000E-07	0.0000000E+00
4.1400000E-07	0.0000000E+00
1.1300000E-06	0.0000000E+00
3.0600000E-06	0.0000000E+00
8.3200000E-06	0.0000000E+00
2.2600000E-05	0.0000000E+00
6.1400000E-05	0.0000000E+00
1.6700000E-04	0.0000000E+00
4.5400000E-04	2.2082066E-06
1.2350000E-03	1.4767409E-03
3.3500000E-03	6.9836863E-03
9.1200000E-03	3.1559581E-02
2.4800000E-02	1.4295802E-01
6.7600000E-02	6.7840900E-01
1.8400000E-01	3.0050409E+00
3.0300000E-01	3.6477621E+00
5.0000000E-01	6.3761669E+00
8.2300000E-01	8.7792370E+00
1.3530000E+00	2.1260986E+01
1.7380000E+00	2.8315218E+01

2.2320000E+00 6.3594080E+01
2.8650000E+00 1.0255261E+02
3.6800000E+00 6.6973087E+01
6.0700000E+00 5.6682928E+00
7.7900000E+00 0.0000000E+00
1.0000000E+01 0.0000000E+00
1.2000000E+01 0.0000000E+00
1.3500000E+01 0.0000000E+00
1.5000000E+01 0.0000000E+00
1.7000000E+01 0.0000000E+00
sc9 pu240 alphas on o 18
si9 sp9
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 0.0000000E+00
4.1400000E-07 0.0000000E+00
1.1300000E-06 0.0000000E+00
3.0600000E-06 0.0000000E+00
8.3200000E-06 3.6619320E-08
2.2600000E-05 1.7284777E-07
6.1400000E-05 4.7068371E-07
1.6700000E-04 1.5325252E-06
4.5400000E-04 4.6094310E-06
1.2350000E-03 1.2543434E-05
3.3500000E-03 3.3968903E-05
9.1200000E-03 1.9482027E-04
2.4800000E-02 9.2768057E-04
6.7600000E-02 4.4454206E-03
1.8400000E-01 1.8801524E-02
3.0300000E-01 2.2891878E-02
5.0000000E-01 3.9556704E-02
8.2300000E-01 5.5522520E-02
1.3530000E+00 1.3999771E-01
1.7380000E+00 1.7898106E-01
2.2320000E+00 3.9499020E-01
2.8650000E+00 6.3911709E-01
3.6800000E+00 4.2092389E-01
6.0700000E+00 3.7038466E-02
7.7900000E+00 0.0000000E+00
1.0000000E+01 0.0000000E+00
1.2000000E+01 0.0000000E+00
1.3500000E+01 0.0000000E+00
1.5000000E+01 0.0000000E+00
1.7000000E+01 0.0000000E+00
sc10 pu242 alphas on o 18
si10 sp10
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 0.0000000E+00
4.1400000E-07 0.0000000E+00
1.1300000E-06 0.0000000E+00
3.0600000E-06 0.0000000E+00
8.3200000E-06 0.0000000E+00
2.2600000E-05 0.0000000E+00
6.1400000E-05 0.0000000E+00
1.6700000E-04 0.0000000E+00
4.5400000E-04 1.8540378E-09
1.2350000E-03 8.9892374E-08
3.3500000E-03 3.4222750E-07
9.1200000E-03 2.0176990E-06
2.4800000E-02 9.8776577E-06
6.7600000E-02 4.4155000E-05
1.8400000E-01 1.9253883E-04
3.0300000E-01 2.2722286E-04
5.0000000E-01 3.0413000E-04
8.2300000E-01 3.5801429E-04
1.3530000E+00 1.2098383E-03
1.7380000E+00 1.6764485E-03
2.2320000E+00 3.8538482E-03
2.8650000E+00 5.7433801E-03
3.6800000E+00 2.9915765E-03
6.0700000E+00 7.8305580E-05
7.7900000E+00 0.0000000E+00
1.0000000E+01 0.0000000E+00

1.2000000E+01 0.0000000E+00
1.3500000E+01 0.0000000E+00
1.5000000E+01 0.0000000E+00
1.7000000E+01 0.0000000E+00

sc11 S.F. pu238
s11 sp11
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 3.4090702E-10
4.1400000E-07 1.1915242E-09
1.1300000E-06 5.3779209E-09
3.0600000E-06 2.3883560E-08
8.3200000E-06 1.0726586E-07
2.2600000E-05 4.8001788E-07
6.1400000E-05 2.1496799E-06
1.6700000E-04 9.6469605E-06
4.5400000E-04 4.3228174E-05
1.2350000E-03 1.9394741E-04
3.3500000E-03 8.6477422E-04
9.1200000E-03 3.8827890E-03
2.4800000E-02 1.7308779E-02
6.7600000E-02 7.6823520E-02
1.8400000E-01 3.3081998E-01
3.0300000E-01 4.4623538E-01
5.0000000E-01 8.7036376E-01
8.2300000E-01 1.5782692E+00
1.3530000E+00 2.5594209E+00
1.7380000E+00 1.6518515E+00
2.2320000E+00 1.7778579E+00
2.8650000E+00 1.7260241E+00
3.6800000E+00 1.4694268E+00
6.0700000E+00 1.6226717E+00
7.7900000E+00 2.3794062E-01
1.0000000E+01 6.5468170E-02
1.2000000E+01 9.6594802E-03
1.3500000E+01 1.4720796E-03
1.5000000E+01 3.8179570E-04
1.7000000E+01 1.0882692E-04

sc12 S.F. pu239
s12 sp12
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 2.8748582E-12
4.1400000E-07 1.0048084E-11
1.1300000E-06 4.5351819E-11
3.0600000E-06 2.0140924E-10
8.3200000E-06 9.0456925E-10
2.2600000E-05 4.0479736E-09
6.1400000E-05 1.8128168E-08
1.6700000E-04 8.1352378E-08
4.5400000E-04 3.6454038E-07
1.2350000E-03 1.6355358E-06
3.3500000E-03 7.2924170E-06
9.1200000E-03 3.2741068E-05
2.4800000E-02 1.4593624E-04
6.7600000E-02 6.4752653E-04
1.8400000E-01 2.7864889E-03
3.0300000E-01 3.7561221E-03
5.0000000E-01 7.3235188E-03
8.2300000E-01 1.3287216E-02
1.3530000E+00 2.1616531E-02
1.7380000E+00 1.4031573E-02
2.2320000E+00 1.5212173E-02
2.8650000E+00 1.4933604E-02
3.6800000E+00 1.2923776E-02
6.0700000E+00 1.4787532E-02
7.7900000E+00 2.3169799E-03
1.0000000E+01 6.7758814E-04
1.2000000E+01 1.0779095E-04
1.3500000E+01 1.7577652E-05
1.5000000E+01 4.8205322E-06
1.7000000E+01 1.4615156E-06

sc13 S.F. pu240
s13 sp13

```
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 3.6503923E-10
4.1400000E-07 1.2758668E-09
1.1300000E-06 5.7585972E-09
3.0600000E-06 2.5574160E-08
8.3200000E-06 1.1485869E-07
2.2600000E-05 5.1399607E-07
6.1400000E-05 2.3018461E-06
1.6700000E-04 1.0329832E-05
4.5400000E-04 4.6288207E-05
1.2350000E-03 2.0767748E-04
3.3500000E-03 9.2600518E-04
9.1200000E-03 4.1578473E-03
2.4800000E-02 1.8536486E-02
6.7600000E-02 8.2288582E-02
1.8400000E-01 3.5445916E-01
3.0300000E-01 4.7810122E-01
5.0000000E-01 9.3167008E-01
8.2300000E-01 1.6840667E+00
1.3530000E+00 2.7075979E+00
1.7380000E+00 1.7255861E+00
2.2320000E+00 1.8303675E+00
2.8650000E+00 1.7398546E+00
3.6800000E+00 1.4373853E+00
6.0700000E+00 1.4917684E+00
7.7900000E+00 1.9510018E-01
1.0000000E+01 4.8445456E-02
1.2000000E+01 6.3021157E-03
1.3500000E+01 8.5809755E-04
1.5000000E+01 2.0295869E-04
1.7000000E+01 5.2281120E-05

sc14 S.F. pu242
#      si14          sp14
0.0000000E+00 0.0000000E+00
1.3900000E-10 0.0000000E+00
1.5200000E-07 3.5574578E-10
4.1400000E-07 1.2433854E-09
1.1300000E-06 5.6119978E-09
3.0600000E-06 2.4923105E-08
8.3200000E-06 1.1193466E-07
2.2600000E-05 5.0091086E-07
6.1400000E-05 2.2432451E-06
1.6700000E-04 1.0066840E-05
4.5400000E-04 4.5109582E-05
1.2350000E-03 2.0238759E-04
3.3500000E-03 9.0239592E-04
9.1200000E-03 4.0515677E-03
2.4800000E-02 1.8059430E-02
6.7600000E-02 8.0133289E-02
1.8400000E-01 3.4478767E-01
3.0300000E-01 4.6445662E-01
5.0000000E-01 9.0396436E-01
8.2300000E-01 1.6324303E+00
1.3530000E+00 2.6261474E+00
1.7380000E+00 1.6781746E+00
2.2320000E+00 1.7874761E+00
2.8650000E+00 1.7107876E+00
3.6800000E+00 1.4285031E+00
6.0700000E+00 1.5180353E+00
7.7900000E+00 2.0792057E-01
1.0000000E+01 5.3889680E-02
1.2000000E+01 7.3969733E-03
1.3500000E+01 1.0574345E-03
1.5000000E+01 2.6034751E-04
1.7000000E+01 7.0101613E-05

print -30
```

SENSMG Input File

```
multiple spont. fiss. and (a,n) sources
sphere 1kg
mt80
1 / no of materials
1 94238 -1.982149 94239 -2990.0 94240 -5.033104 94242 -2.984747 8016 -400.476171 8017 -0.163623
8018 -0.923840 /
-9.533052 /
1 / no of shells
4.40 / radii
1 / material nos
0 / number of edit points
0 / number of reaction-rate ratios
0 / number of njoy reactions
```

SOURCES4C Input File

```
multiple spont. fiss. and (a,n) sources mat      1
1 2 -1
2 0
 094  3.3333365E-01
 008  6.6666635E-01
-30 1.70000E+01 1.39000E-10
 1.70000E+01 1.50000E+01 1.35000E+01 1.20000E+01 1.00000E+01
 7.79000E+00 6.07000E+00 3.68000E+00 2.86500E+00 2.23200E+00
 1.73800E+00 1.35300E+00 8.23000E-01 5.00000E-01 3.03000E-01
 1.84000E-01 6.76000E-02 2.48000E-02 9.12000E-03 3.35000E-03
 1.23500E-03 4.54000E-04 1.67000E-04 6.14000E-05 2.26000E-05
 8.32000E-06 3.06000E-06 1.13000E-06 4.14000E-07 1.52000E-07
4
 0942380  1.4053135E+19
 0942390  2.1109736E+22
 0942400  3.5386016E+19
 0942420  2.0810939E+19
2 100
 0080170  2.5566745E-04
 0080180  1.3633371E-03
```